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NOISE AND SONIC BOOM IMPACT TECHNOLOGY

PCBOOM Computer Program for Sonic Boom Research: Program Users/Computer Operations Manual

Volume II of III Volumes

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This report contains the information for both the user and for computer operations. The report provides the user with the information necessary to effectively use PCBOOM. In addition, it provides the computer operations personnel with a description of the computer system and its associated environment. Two other reports provide a technical discussion of the algorithms used and a program maintenance manual. Keywords:

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EXECUTIVE SUMMARY

The PCBOOM computer program calculates the location and magnitude of sonic boom overpressures on the ground due to supersonic flights of military aircraft under standard atmosphere conditions and no wind propagation conditions. The program should be useful to the planner or engineer concerned with estimating the overpressures resulting from single aircraft flights.

The program is written to run on a Zenith Z-248 personal computer running under MS DOS Version 3.0 or greater with at least a 10 megabyte hard disk , 640K RAM and an 8087 math coprocessor. The program should also run on most similarly configured IBM-compatible computers.

The user can select two types of calculations: "quick look" computations which assume steady-state flight and do not account for any focusing of booms; or computations based on detailed ray tracing calculations which do handle focus boom situations. The quick look method may take several minutes to calculate, while the ray tracing method may take many hours.

The user can specify aircraft and aircraft operating conditions for several types of simple maneuvers ranging from straight line flight, with or without changes in speed or altitude, to turns at constant speed, with or without changes in altitude. The program will also handle the computations for connected straight line flight segments (up to ten).
The user may also select flight segments from the MOAOPS library of supersonic combat training flights as input.

Program output may be displayed on the computer monitor screen, or printed or plotted on 8-1/2 by 11 inch paper. Several output forms may be chosen:

1) Tables of overpressure versus distances along and perpendicular to the flight track;
2) A plot of the overpressure versus distance perpendicular to the flight track (for a single flight track point only);
3) A graphic display of the sonic boom overpressure "footprint" on the ground. The "footprint" display shows the location of all ray positions which exceed overpressures of a given level for each successive flight track position for which calculations are made. Thus, the display provides an outline of the areas exposed to overpressure of a given level and also clearly indicates the location of the areas exposed to augmented or focused booms.

In addition, the user may obtain plots of the flight track, Mach number and altitude profiles generated by the user inputs.

1.0 INTRODUCTION

The PCBOOM computer program provides a means for calculating the location and the magnitude of sonic boom overpressures on the ground resulting from supersonic flights of military aircraft under standard atmosphere (Ref. 1) and no wind propagation conditions. The program is written to run on a Zenith Z-248 personal computer running under MS DOS Version 3.0 or greater with at least a 10 megabyte hard disk, 640K RAM and an 8087 math co-processor. The program should also run on most similarly configured IBM- compatible computers.

The PCBOOM program may be useful to the planner for estimating the sonic boom overpressures for proposed supersonic operations. The program may also be useful for engineering applications involving the analysis of overpressures resulting from single aircraft flights.

The user can usually select two different types of calculations:

1) "Quick look" computations based on the methods developed by Carlson (Ref. 2) assuming steady-state flight. This method does not account for any focusing;
2) Computations based on detailed ray tracing techniques. These techniques allow for calculation of the location and magnitude of sonic boom focus effects. The ray tracing routines are based upon the modified TRAPS program (Ref.3) as incorporated in the BOOMAP2 program (Ref. 4) developed for mainframe computers.

The program allows the user to specify aircraft and aircraft operating conditions for several types of simple maneuvers. The user may also select a single flight segment from the MOAOPS library of supersonic combat training flights (Ref. 5). Input to the program is entered from user-friendly interactive screens.

Several forms of output may be chosen by the user:

1) Tables of the overpressure versus distances along and perpendicular to the flight track for a single flight track point (Carlson's method only);

2) Graphic plot of the overpressure versus distance perpendicular to the flight track (Carson's method only);

3) Graphic display of the sonic boom overpressure "footprint" on the ground. The "footprint" display provides an outline of the area exposed to overpressures of a given level or greater.

In addition, the user may choose to obtain plots of the flight track, Mach number profile and altitude profile generated from the user inputs.

This report is one of three documents describing the PCBOOM program. The others consist of a user's guide (Ref. 6) and a maintenance manual (Ref. 7).

The next section of this report presents an overview of the PCBOOM program. Section 3 describes various technical aspects of the program. The appendix provides some examples of program output.

2.0 PROGRAM OVERVIEW

2.1 Program Hardware and Software

As noted earlier, PCBOOM has been developed to run on a Zenith Z-248 personal computer running under MS DOS Version 3.0 or greater, with at least a 10 megabyte hard disk, 640 K RAM and an 8087 math co-processor. It should also run on most IBM-compatible computers that are similarly configured. The software runs best with an enhanced graphics adapter (EGA) card or a color graphics adapter (CGA) card. A Hercules-compatible graphics card may be used but the plots are not as distinct and the input screens are not as easy to use.

The program is written in ANSI 77 FORTRAN. A commercially-available software program, SPINDRIFT (Ref. 8), is used to provide user-friendly input screens. Routines from another commercial software program, PLOT88 (Ref. 9), are incorporated to provide graphic X-Y plots.

The program uses approximately 610K of computer memory. With this memory constraint; each execution of PCBOOM is limited to a maximum of 98 flight track points.

The amount of execution time varies depending upon the type of computations selected. With the Carson method, most runs will execute in 1 to 2 minutes without footprint displays, and 4 to 7 minutes with footprints. With ray-tracing computations, the execution times can be between 45 minutes to 48 hours. An estimate of the computation time is provided on the screen prior to the execution of a ray-tracing run so that the user can decide whether to proceed with the job.

All outputs are displayed on the computer's monitor, or printed or plotted on 8-1/2 by 11 inch paper.

2.2 Data Input to Program

All user inputs to the PCBOOM program are prompted from a series of "screens". Seventeen screens are used. Figure 1 identifies the screens. The figure also indicates the flow between screens. Each of the screens is discussed in Reference 6.

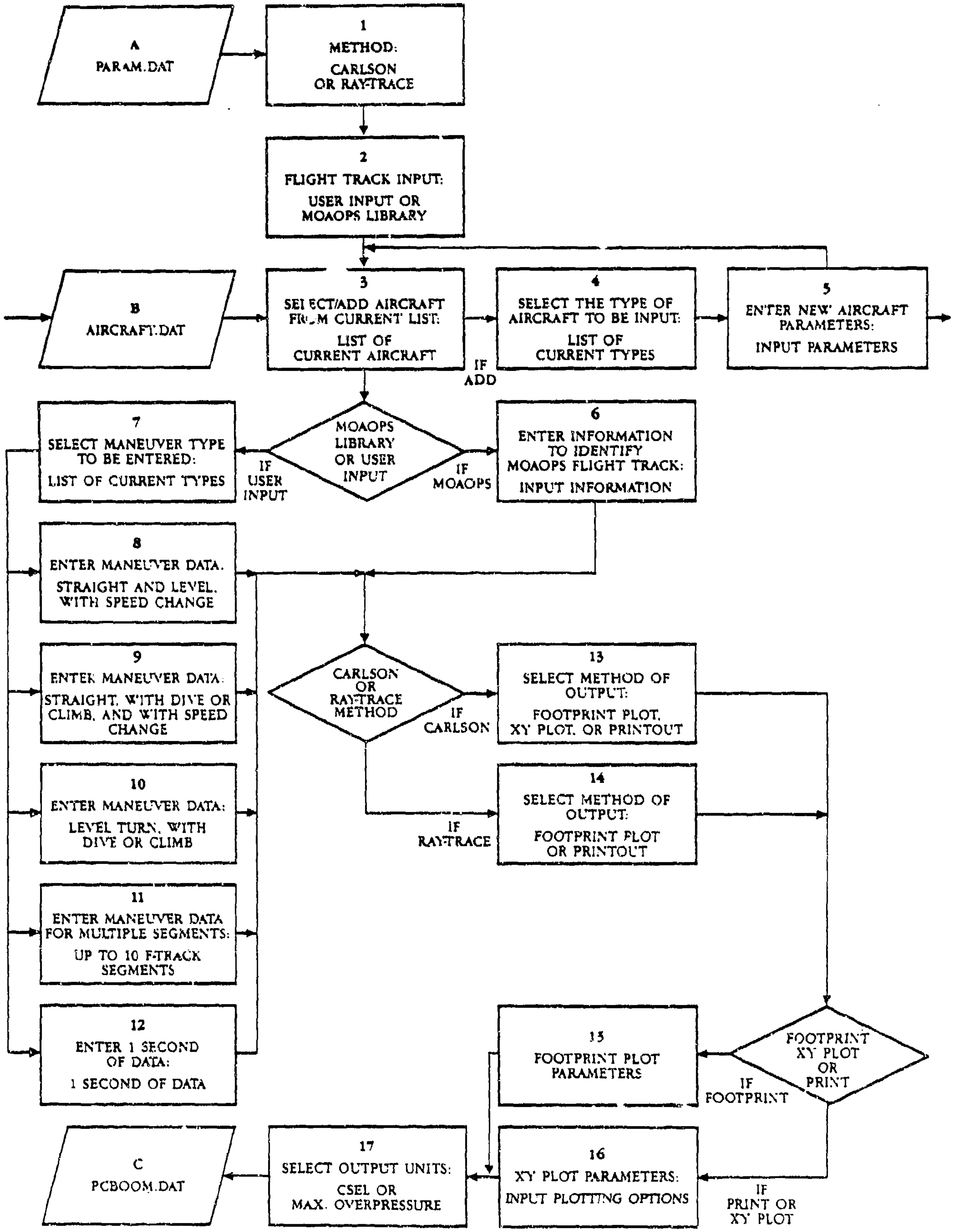

FIGURE 1. PCBOOM PROGRAM FLOW CHART

3.0 TECHNICAL OVERVIEW

3.1 Measures of Sonic Boom Strength and Duration

The user may choose between two measures of the sonic boom "strength": the C-weighted sound exposure level (CSEL) in dB, or the maximum overpressure of the boom in pounds per square foot (psf). The CSEL is calculated from the maximum flat-weighted sound pressure level (OASPL) in dB as follows:

$$CSEL = OASPL - 26 \qquad (dB)$$

or, alternatively:

$$CSEL = 10 * \log_{10} (p)^2 + 101.6 \qquad (dB)$$

where p is the maximum overpressure in psf. A reflection factor of 2.0 (perfect reflection from the ground surface) has been assumed in the calculations.

The signal duration is measured in seconds.

3.2 Application of Carlson's Equations

The procedures and equations developed by Carlson (Ref. 2) provide a reasonably accurate method for predicting the sonic boom overpressures and signal durations for steady flight. For PCBOOM, these equations have been adopted directly in a straight-forward manner[1], except for two modifications discussed below. Interpolation of values that vary with altitude (and which are presented in graphs by Carlson) is typically done within the program by means of table look-up, rather than by curve fitting.

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[1] Errors discovered on pages 16 and 21 of Ref. 2 have been corrected.

The basic Carlson equations have been modified for predictions at lower altitudes using the adjustments of Plotkin (Ref. 10). These adjustments reduce the overpressures and increase the durations calculated by the basic Carlson equations at lower altitudes. Figure 2 (adopted from Ref. 10) compares overpressures calculated from the modified model, the Carlson equations, and from a full-signature ray tracing model.

The second modification that has been incorporated in the PCBOOM calculations modifies the calculated overpressures to the side on the flight path in the vicinity of the nominal cutoff distance and beyond. At or near the nominal lateral cutoff distance, experimental measurements have indicated rather sharp decreases in sonic boom overpressure with the wave shape disintegrating into a ragged sine shape. To depict the variation in CSEL and maximum overpressure as a function of distance in the vicinity of cutoff, a general curve has been assumed that is consistent with the assumptions employed in References 4 and 5.

Beginning at a sideline distance equal to 0.8 times the calculated cutoff distance, the CSEL and overpressure values are modified so that the levels at the cutoff distance are 10 dB lower than at the 0.8 cutoff point. Beyond cutoff, levels are assumed to decrease at a rate of 25 dB per decade distance. Calculations are normally terminated at a distance 1.2 times the calculated cutoff distance. Figure 3 provides an example of the resulting variation of CSEL values versus sideline distance.

As noted above, the Carlson equations assume steady, straight-line flight. They require aircraft information (see Section 3.3 below), and specification of the aircraft Mach number, altitude and climb/dive angle, and the ground height.

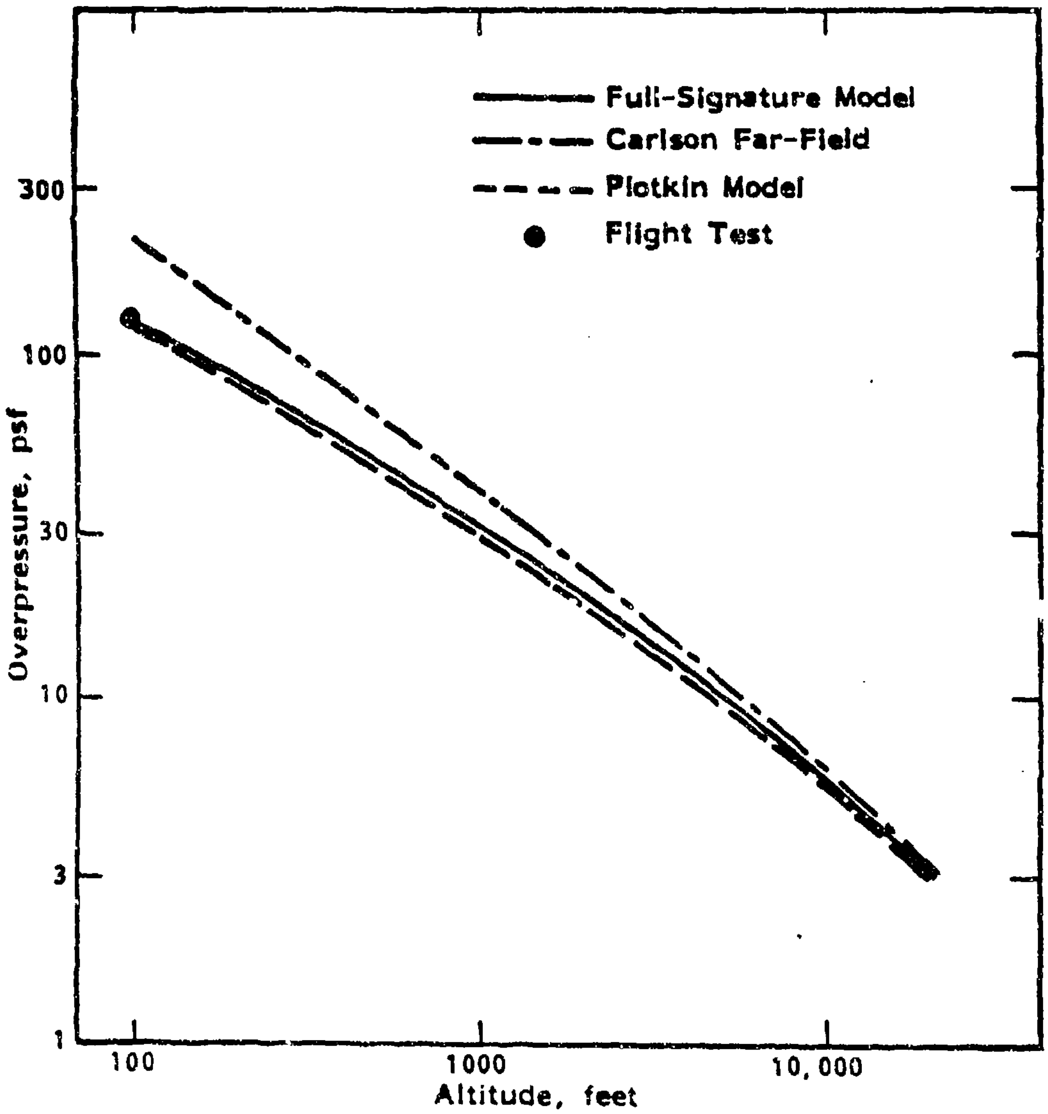

Figure 2. Comparison Between Full-Signature Boom Model, Carlson Far-Field Model, and Plotkin Modifications to Carlson Model

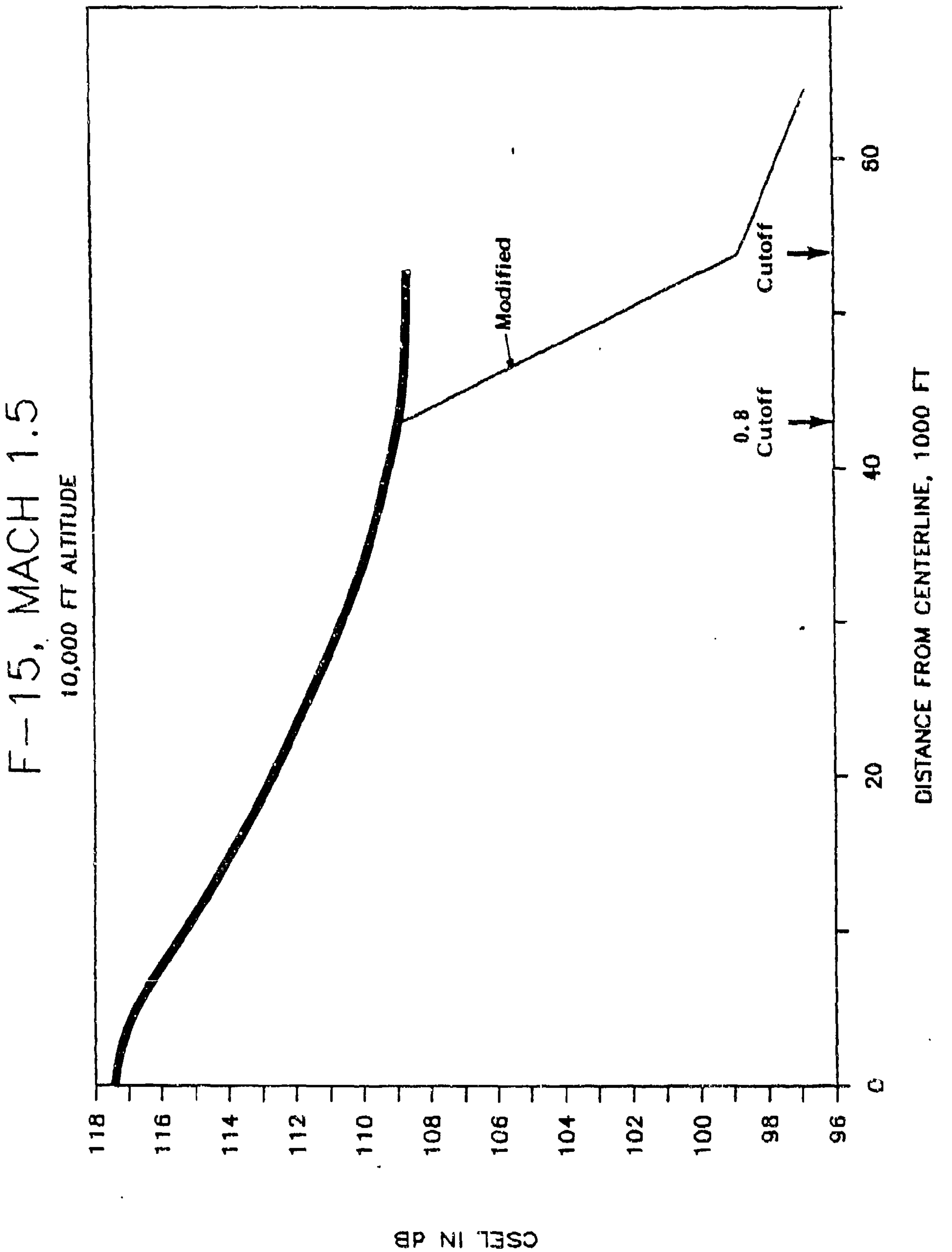

FIGURE 3. EXAMPLE OF MODIFICATIONS TO CARLSON PREDICTIONS IN THE VICINITY OF SONIC BOOM CUTOFF

In PCBOOM, the user may choose to use the Carlson equations for non-steady flight involving accelerations and turns. In such cases, the Carlson equations are applied at successive points along the flight track (with acceleration and turn information ignored in the computations except as needed to determine flight track positions and aircraft speed, altitude and climb/dive attitude at each position). In such cases, the Carlson results may be subject to considerable error. However, because the calculations can be completed quickly, the results may often be useful in indicating the approximate location of potential focus points on the ground, and in providing reasonable estimates of the overpressures at positions away from focus locations.

3.3 Aircraft Information for Sonic Boom Calculations

The PCBOOM program stores aircraft information needed for sonic boom calculations for 18 aircraft. In addition, means are provided for adding information for new aircraft.

A sonic boom program must be provided with a description of the disturbance of the atmosphere generated by the flight of the supersonic airplane. This disturbance may be described in terms of the overpressure wave form that an observer near the aircraft would measure as the aircraft flies by, or equivalently, in terms of numbers based upon a theoretically derived F-function defining the flow near the aircraft. For PCBOOM, simplified F-function values are used, based on the methods developed by Carlson (Ref. 1). In the calculations, aircraft-dependent lift factors and shape factors are employed which are derived from the equations and charts provided by Carlson. Table 1 lists the aircraft shape factors currently incorporated in the PCBOOM program.

TABLE 1

AIRCRAFT SHAPE FACTOR IN THE CURRENT PCBOOM PROGRAM

Aircraft	Length	Weight	S-Factor
F-4	58.20ft	56.00K lbs	.0880
F-5	46.60	19.60	.0642
F-8	54.50	32.30	.0870
F-14	62.70	56.70	.0873
F-15	63.80	42.30	.0838
F-16	47.60	23.30	.0838
F-18	56.00	49.30	.0900
F-20	46.50	26.10	.0643
F-101	71.10	48.40	.0860
F-104	54.80	21.40	.0642
F-105	64.20	42.70	.0860
F-106	70.80	34.20	.0840
F-111	75.50	95.00	.0892
RECON	107.28	181.40	.0870
RF-4	63.00	55.10	.0880
SR-71	107.40	161.00	.0870
T-38	46.30	11.20	.0642
B-1B	147.00	453.00	.0910

Note that the F-function approach adopted in the PCBOOM calculations represents a simplification of actual situations, because the actual F-functions change with aircraft accelerations and also vary with altitude and speed. However, these changes generally are small compared with other uncertainties in the calculations and are not critical unless one is concerned with making detailed calculations for specific test conditions.

3.4 Ray Tracing Sonic Boom Calculations

The PCBOOM program provides the option of calculating sonic boom overpressures and durations using a sophisticated ray-tracing program that, unlike the Carlson equations, can handle focus and near-focus booms that may arise from non-steady flight. The ray-tracing program incorporated in PCBOOM is based on the TRAPS[3] program (Ref. 3) developed by Dr. Albion Taylor of the National Oceanic and Atmospheric Administration (NOAA). However, the version of the TRAPS program incorporated in BOOMAP2 (and in PCBOOM) incorporates several corrections to the original program; it also includes several additions to permit estimation of overpressures at focus locations. Reference 4 provides a technical overview of the modified program which is incorporated in PCBOOM.

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3 The TRAPS designation comes from "Tracing Rays and Aging Pressure Signatures".

3.5 PCBOOM Calculation Options

The PCBOOM program allows selection of a flight extracted from the MOAOPS data base or the user may select a maneuver (Screen 2). Any of six maneuver types may be selected (Screen 7):

1) Straight and level, with speed change
2) Straight flight, dive/climb, with speed change
3) Constant turn, level flight, with constant speed
4) Constant turn, dive/climb, at constant speed
5) Connected straight flight track segments (up to ten in number)
6) Snapshot at a single flight track point (Carlson calculations only)

In the calculations for each of the first three maneuvers, the user may, as an option, specify "entry" and "exit" segments which are straight flight track segments of constant speed and altitude. In maneuver type four, all flight track positions lie on the same plane (to avoid complicated geometrical calculations), hence the "entry" and "exit" segments usually will not be at the same altitude.

For the first five maneuver types listed above, the sonic boom calculations are made at flight track positions spaced one second apart. In maneuver type five (connected line segments), calculation positions are spaced equally within a segment, but the spacing (and time) between positions may vary between segments.

It should be noted that the transitions from "entry" to "maneuver" and from "maneuver" to "exit" segments may result in a sonic boom focus on the ground. Thus the interpretation of the footprint must take into account the impact of these segments. Hence, in many cases, the user may not wish to add the "entry" and "exit" segments.

Of course, the non-steady conditions of the maneuver segment may also result in a sonic boom focus on the ground. Similarly, the transition from one flight track segment to another (in maneuver type 5) may also result in focusing.

Samples of the output for each of the maneuver options is provided in the appendix.

3.6 Footprint Displays

The original intent in developing PCBOOM was to present displays of the sonic boom overpressure under and to the sides of the flight track by means of "contours"--continuous lines connecting points of equal sound levels. This means of displaying the variation of sound levels over land areas is widely and successfully used for handling subsonic aircraft noise and noise from surface vehicles (motor vehicle and train traffic for example). Considerable effort was devoted to adapting this method of display to the different maneuvers encompassed within the PCBOOM program capabilities. The resulting contours that were calculated showed major errors and difficulties in interpretation (except for some cases of flight track segments that were many miles long).

Review of the trial contour plots, and comparison of the plots with the calculated overpressure values, indicates two major factors that result in unsatisfactory contour displays.

The foremost reason is that the overpressure values calculated for one flight track position may overlap those calculated at other flight track positions. This situation occurs frequently for any maneuver other than steady flight. It results in erratic and large variations in overpressure within ground areas that are very small compared with total area exposed to sonic booms (and small compared to the grid spacing used by the contouring program). These large and erratic variations in overpressures violate two assumptions of typical contouring programs:

a) that the overpressures (z-values) vary in a smooth and continuous manner over the grid of x- and y- values; and

b) that the variation in overpressures within distance intervals equal to the grid spacing is moderate.

Another reason contributing to the contouring problem is that, for many of the maneuvers, the ground areas over which overpressures are calculated are very "narrow" (i.e., large in the y-direction compared to the x-direction) and are also small compared to the area covered by the contour plot (which typically includes the flight track and the area exposed to the sonic boom).

To overcome these difficulties, an alternate method of displaying "footprints" was chosen which provides much of the information conveyed by "contours" and avoids the computational difficulties discussed above. This approach consists of:

a) plotting the location of all overpressure values that exceed a specified level for each flight track position for which overpressure calculations are made;

b) drawing a line to connect all the overpressure points (selected as in (a) above) that were calculated at any one flight track position. Separate lines are drawn for each flight track position.

For steady, level flight the above process results in a series of equally-spaced parabolas. For non-steady flight the "parabolas" may become distorted, change shape and spacing, and may overlap. The extent of the overlaps indicates areas where enhancement or focusing of sonic booms is occurring.

The process is then repeated, selecting all values that are five dB greater than the initial value. Thus, the complete footprint printout for any single maneuver will include several plots, each one successively covering a smaller area, reflecting the "threshold" value that increases by five dB for each plot.

The program searches out and prints the maximum and minimum calculated overpressure for each maneuver. It then selects the beginning threshold level for the first (and largest) footprint plot as the nearest five dB value falling <u>below</u> the minimum calculated value. Succeeding plots use threshold values that increase in five dB steps, until a threshold value is reached that is less than five dB below the maximum calculated overpressure. The program will typically produce two to four footprint plots per maneuver.

Examples of the footprint plots are shown in the appendix.

4.0 RECOMMENDATIONS FOR FUTURE WORK

Much of the success or failure of any software program rests upon how well the program meets user needs. Similarly, the type and extent of any program improvements or additions should be largely governed by user needs and comments. Hence, the recommendations for future work given here are subject to modification and replacement based upon response from future program users.

One important program modification that would be useful for engineering applications is to extend the ray-tracing computations to handle real-life temperature and wind profiles. This addition requires review of the modified TRAPS program coding to insure that the changes that have been made to the original code will still accommodate wind profiles (which can introduce additional asymmetry in the ray calculations).

Another addition that would augment the footprint display incorporated in the current program is a z- versus x- plot (aircraft height above ground versus flight track) to show the relative location of the beginning and end points of rays emitted directly under the aircraft. The plot would show a line connecting the beginning and end points of such rays, one for each point along the flight track. The relative spacing and orientation among successive rays would graphically show the location of augmented or focused booms at positions directly under the flight path.

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APPENDIX

APPENDIX

This appendix presents examples of the PCBOOM program output for each of the types of maneuver calculations that are available (see Section 3.5). These examples help illustrate the different types of maneuvers and output displays that are available to the user.

Figures A-1, A-2 and A-3 illustrate the output for the single flight track point "snapshot" calculations. Figure A-1 shows the title sheet which summarizes the input conditions. Figure A-2 shows the printed table output. Note that this table provides information on both the maximum overpressure and the CSEL. It also provides both the x- and y-distances which describe the location of the boom on the ground with reference to the aircraft position. Figure A-3 shows a plot of the CSEL values for distances perpendicular to the flight track (y-distances). The user has the option of plotting either CSEL or overpressure values for this and other maneuver calculations.

Figures A-4, A-5 and A-6 present sample output for straight and level flight, with speed change. Figure A-4 summarizes the input information. Note that the ray-trace option was selected in this example. Figure A-5 shows a plot of the Mach number profile. Figures A-6(A) and A-6(B) show two examples of the footprint output. Figure A-6(a) shows the footprint for all data, while Figure A-6(B) shows the footprint for CSEL values of 95 dB or greater. "Crosses" on the figures denote the location of sonic boom focus points on the ground. In this example, level flight "entry"and "exit" flight track segments were specified as an option.

Figures A-7, A-8 and A-9 show output for straight flight with both a speed and altitude change. Figure A-7 summarizes the input conditions. Figure A-8 shows a plot of the altitude profile. Figures A-9(A) and A-9(B) show footprint plots for all data (Figure A-9(A)) and for CSEL values of 100 dB or greater (Figure A-9(B)).

Figures A-10, A-11 and A-12 provide sample output for a constant speed turn in level flight. Figure A-10 summarizes the input conditions. Figure A-11 shows the flight track plot. Figures A-12(A) and A-12(B) show two examples of the footprint output. Figure A-12(A) is the footprint for all data while Figure A-12(B) shows the footprint for CSEL values of 100 dB or greater. In Figure 12, note that the "entry" and "exit" segments increase the number of focus points on the ground.

Examples of output for a turn combined with an altitude change are shown in Figures A-13, A-14, A-15 and A-16. Figure A-13 summarizes the input conditions. Figure A-14 shows the flight track, while Figure A-15 shows the altitude profile. Figure A-16(A) and A-16(B) show two examples of footprint output. Figure A-16(A) is the footprint for all data while Figure A-16(B) shows the footprint for CSEL values of 100 dB and higher.

Figures A-17 through A-20 show examples of output for the connected straight line segment calculations. Figure A-17 summarizes the input conditions for a four-segment example. Figures A-18 and A-19 show plots of the Mach number and altitude profiles for the four segments. The footprint output for all CSEL data is shown in Figure A-20.

PCBOOM COMPUTER PROGRAM

OUTPUT EXAMPLES

CARLSON METHOD

CSEL ¦ F-15 ¦ SNAPSHOT - 1 SEC ¦ 5/31/1988 ¦ 11:37:19

AIRCRAFT
****

F-15

42.30 KLBS

63.80 FT

SHAPE FACTOR : 0.0838

USER INPUT
****

ALTITUDE : 25000.0 FT

GROUND HEIGHT : 0.0 FT

MACH NUMBER : 1.30

FLIGHT TRACK ANGLE : -10.00 DEGREES

LATERAL XY-PLOT PARAMETERS
****

POINT INTERVAL BETWEEN PLOTS : 1

FACTOR SIZE : 1.00

FIGURE A-1. TITLE SHEET FOR SINGLE FLIGHT TRACK POINT "SNAPSHOT" EXAMPLE

SONIC BOOM OVERPRESSURE RESULTS ! F-15

MACH :	1.30	FLIGHT PT. :	1
LENGTH :	63.80(FT)	WEIGHT :	42.30(KLBS)
GROUND HEIGHT :	.00(FT)	ALTITUDE :	25000.(FT)
FLIGHT PATH ANGLE :	-10.00(DEG)	CUTOFF :	62405.(FT)

LATERAL DISTANCE	FORWARD DISTANCE	BOW SHOCK OVERPRESSURE	CSEL	SIGNATURE DURATION
.0	23350.2	2.56	109.76	.120
4113.7	23777.1	2.53	109.65	.120
8224.4	25023.5	2.44	109.36	.121
12336.7	27003.3	2.32	108.92	.123
16468.7	29614.8	2.18	108.38	.124
20654.3	32773.8	2.04	107.80	.126
24945.6	36433.5	1.90	107.20	.129
29419.1	40598.8	1.78	106.59	.131
34194.8	45347.1	1.66	105.98	.134
39487.5	50887.6	1.54	105.37	.137
45787.6	57779.4	1.44	104.76	.140
49853.8	62371.1	1.39	104.44	.143
62408.5	76548.5	.44	94.44	.143
74890.3	90643.5	.35	92.46	.143

FIGURE A-2. TABLE PRINTOUT FOR SINGLE FLIGHT TRACK POINT "SNAPSHOT" EXAMPLE

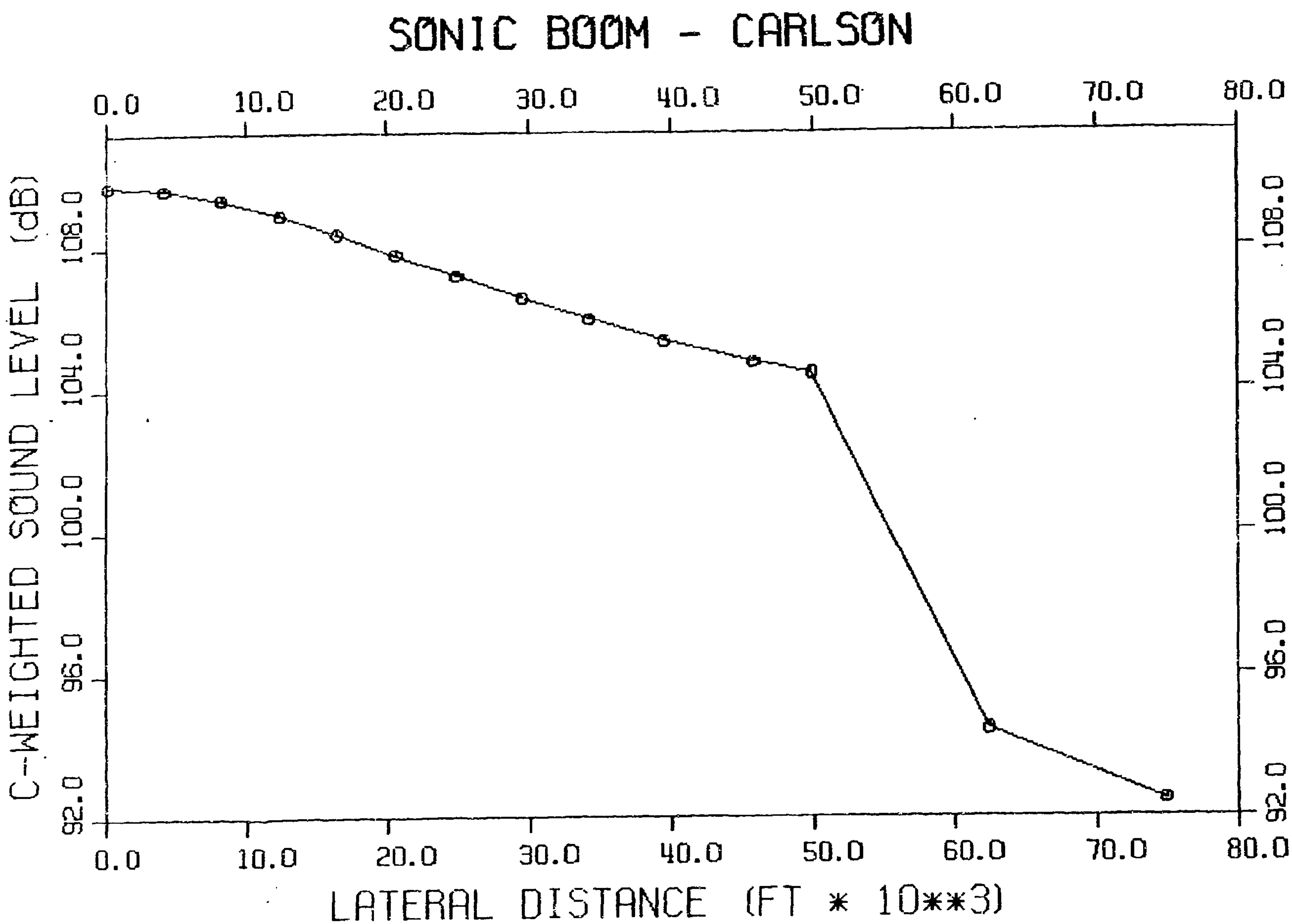

FIGURE A-3. SIDELINE LEVELS FOR SINGLE FLIGHT TRACK POINT "SNAPSHOT" EXAMPLE

```
                RAY-TRACE METHOD
CSEL | F-16   | STRGHT-LVL-ACCEL | 5/28/1988 | 17:41:48

AIRCRAFT
********
F-16
23.30 KLBS
47.60 FT
SHAPE FACTOR : 0.0838

USER INPUT
**********
ALTITUDE              :25000.0 FT
GROUND HEIGHT         :3000.0 FT
BEGINNING MACH        :1.10
ENDING MACH           :1.30
ACCELERATION IN G'S   :0.50
```

FIGURE A-4. TITLE SHEET FOR STRAIGHT AND LEVEL FLIGHT WITH SPEED CHANGE EXAMPLE

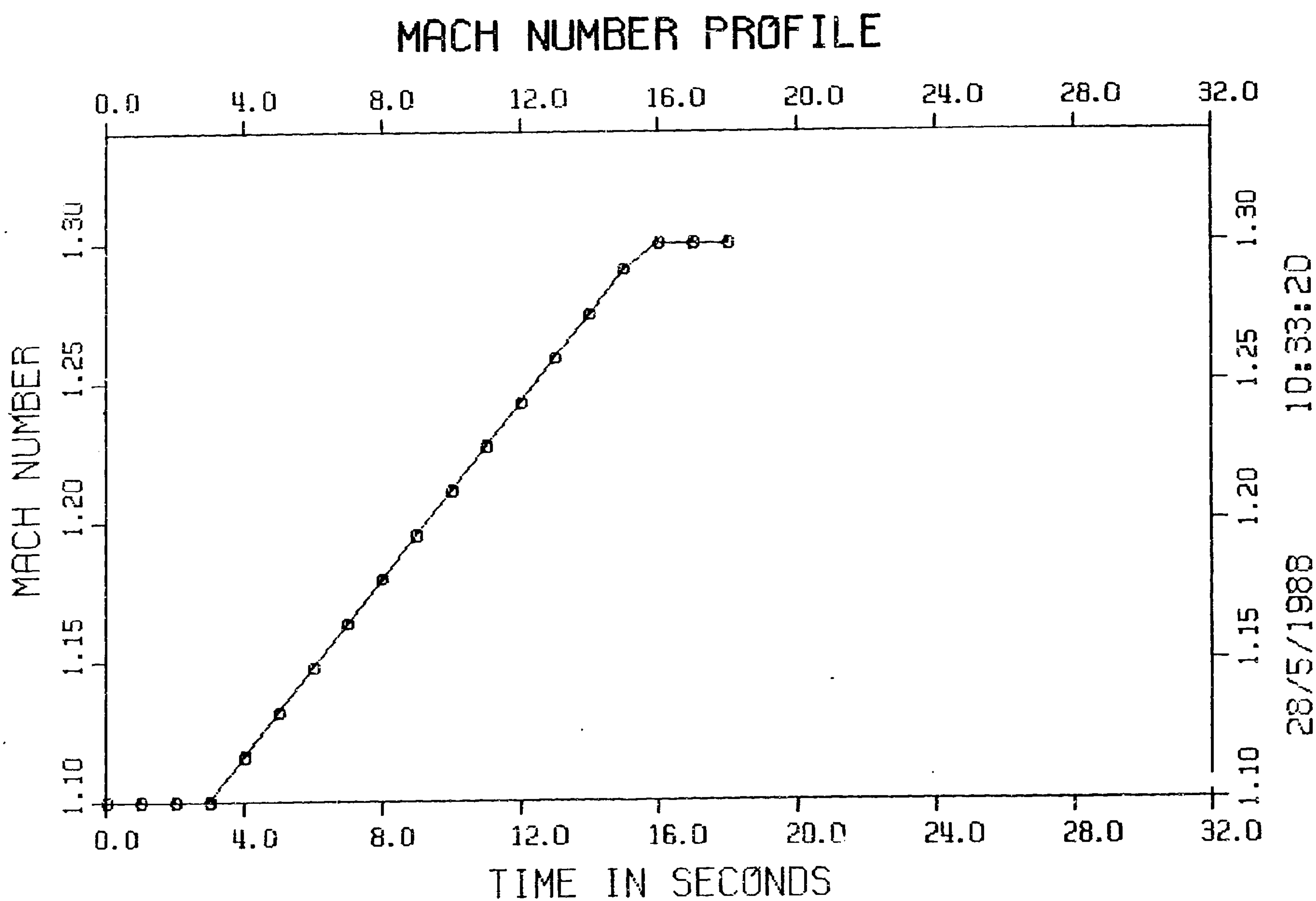

FIGURE A-5. MACH NUMBER PLOT FOR STRAIGHT AND LEVEL FLIGHT WITH SPEED CHANGE EXAMPLE

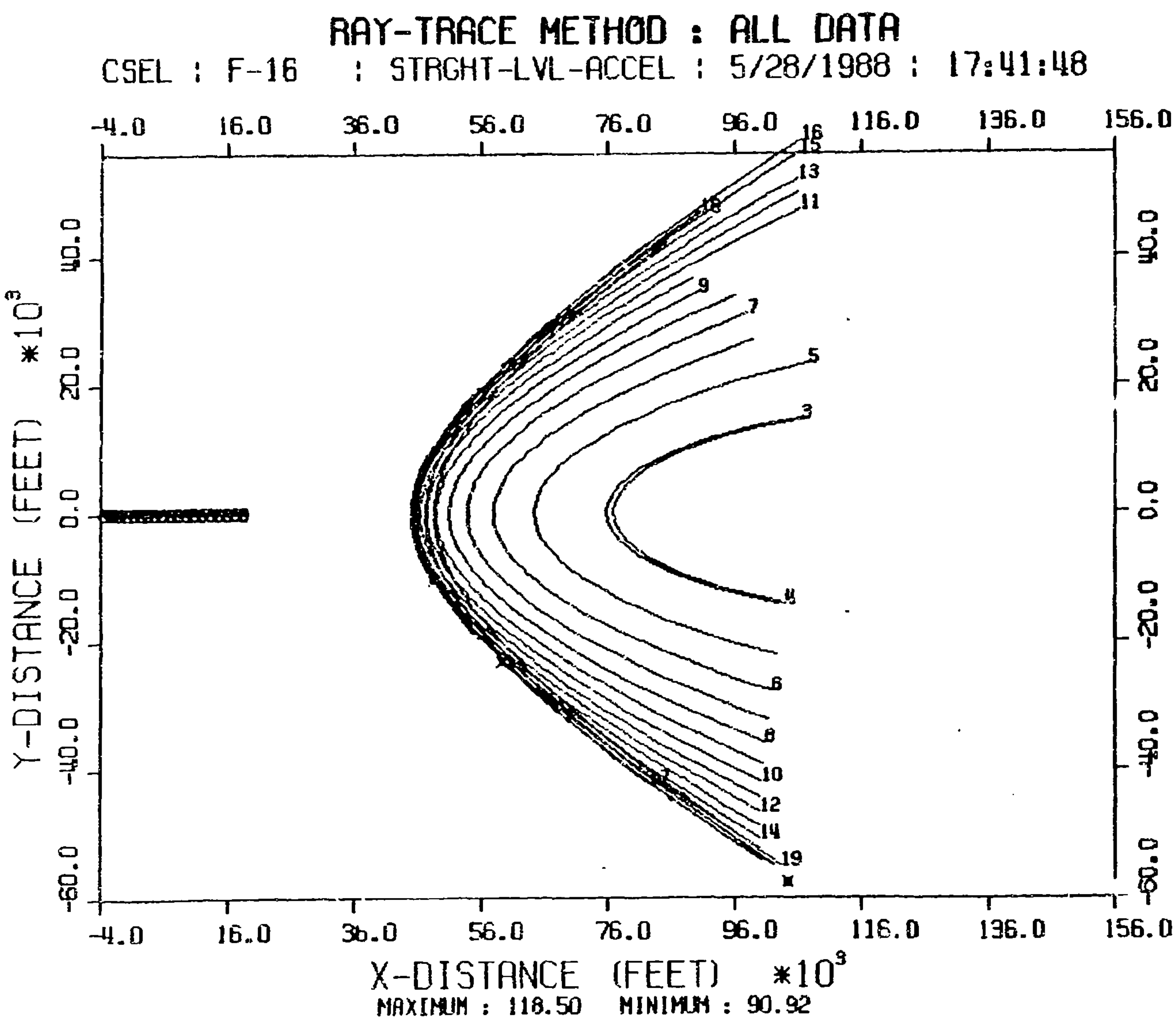

FIGURE A-6(a). FOOTPRINT PLOT FOR STRAIGHT AND LEVEL FLIGHT WITH SPEED CHANGE EXAMPLE

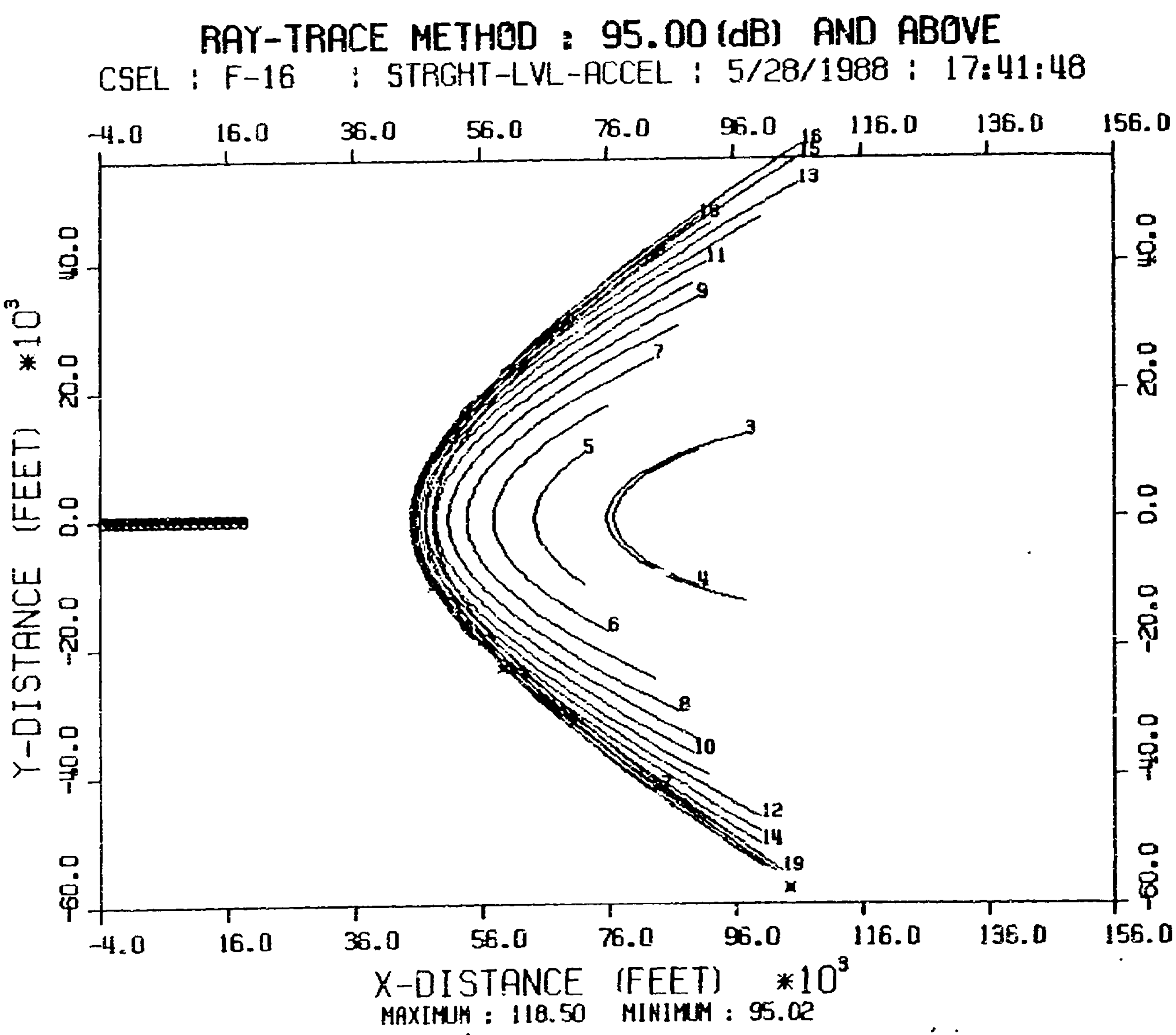

FIGURE A-6(b). FOOTPRINT PLOT FOR STRAIGHT AND LEVEL FLIGHT WITH SPEED CHANGE EXAMPLE

```
                      CARLSØN METHØD
CSEL | F-15   | STRGHT-D/C-ACCEL | 5/31/1988 | 14:25:27


AIRCRAFT
********
F-15
42.30 KLBS
63.80 FT
SHAPE FACTØR : 0.0838

USER INPUT
**********
ALTITUDE                       : 30000.0 FT
GRØUND HEIGHT                  : 3000.0 FT
BEGINNING MACH                 : 1.20
ENDING MACH                    : 1.40
ACCELERATIØN IN G'S            : 0.50
INITIAL FLIGHT TRACK ANGLE     : 0.00 DEGREES
MANEUVERS FLIGHT TRACK ANGLE   : -10.00 DEGREES
ENDING FLIGHT TRACK ANGLE      : 0.00 DEGREES
```

FIGURE A-7. TITLE SHEET FOR STRAIGHT FLIGHT WITH DIVE AND SPEED CHANGE EXAMPLE

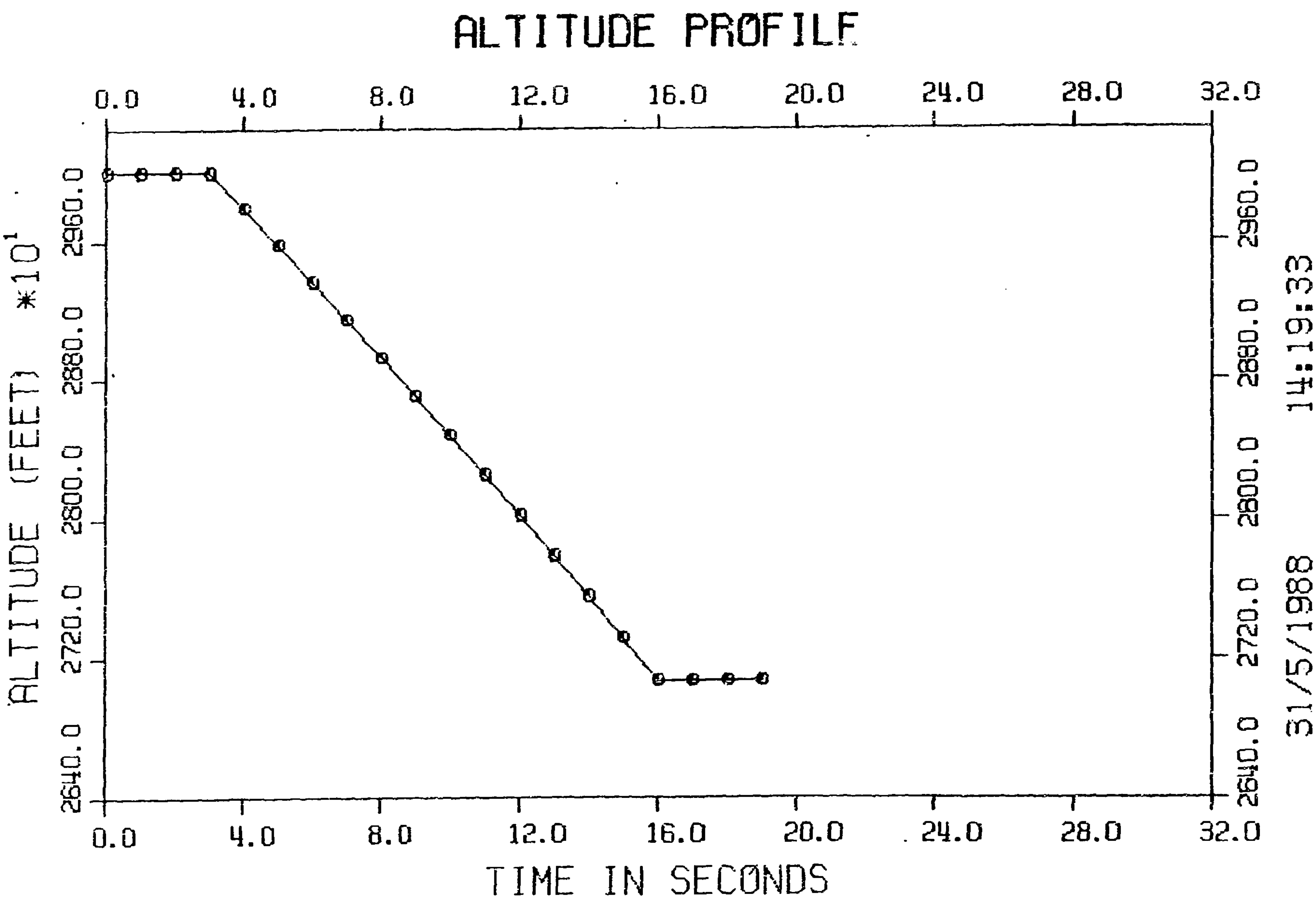

FIGURE A-8. ALTITUDE PROFILE FOR STRAIGHT FLIGHT WITH DIVE AND SPEED CHANGE EXAMPLE

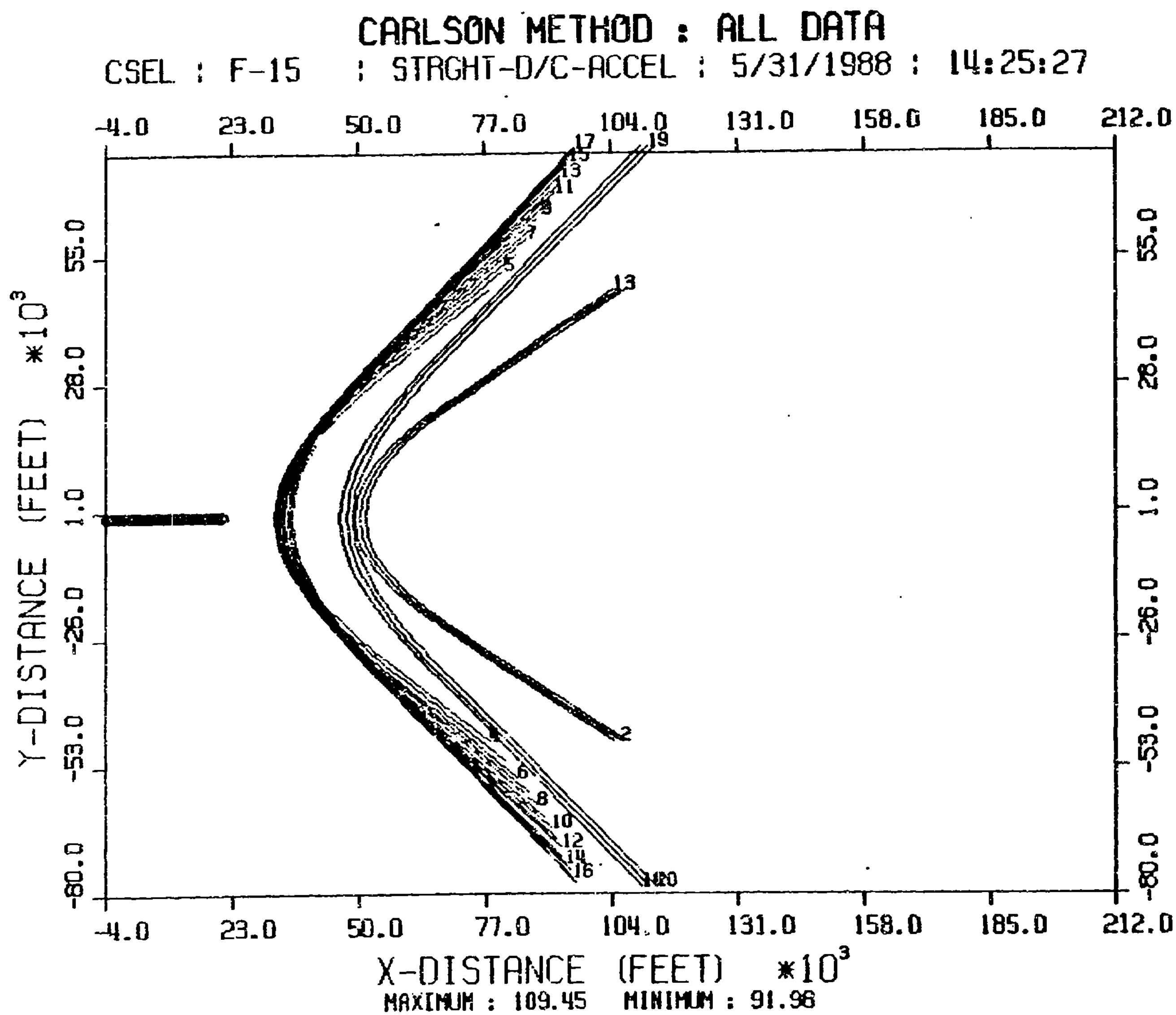

FIGURE A-9(a). FOOTPRINT PLOT FOR STRAIGHT FLIGHT WITH DIVE AND SPEED CHANGE EXAMPLE

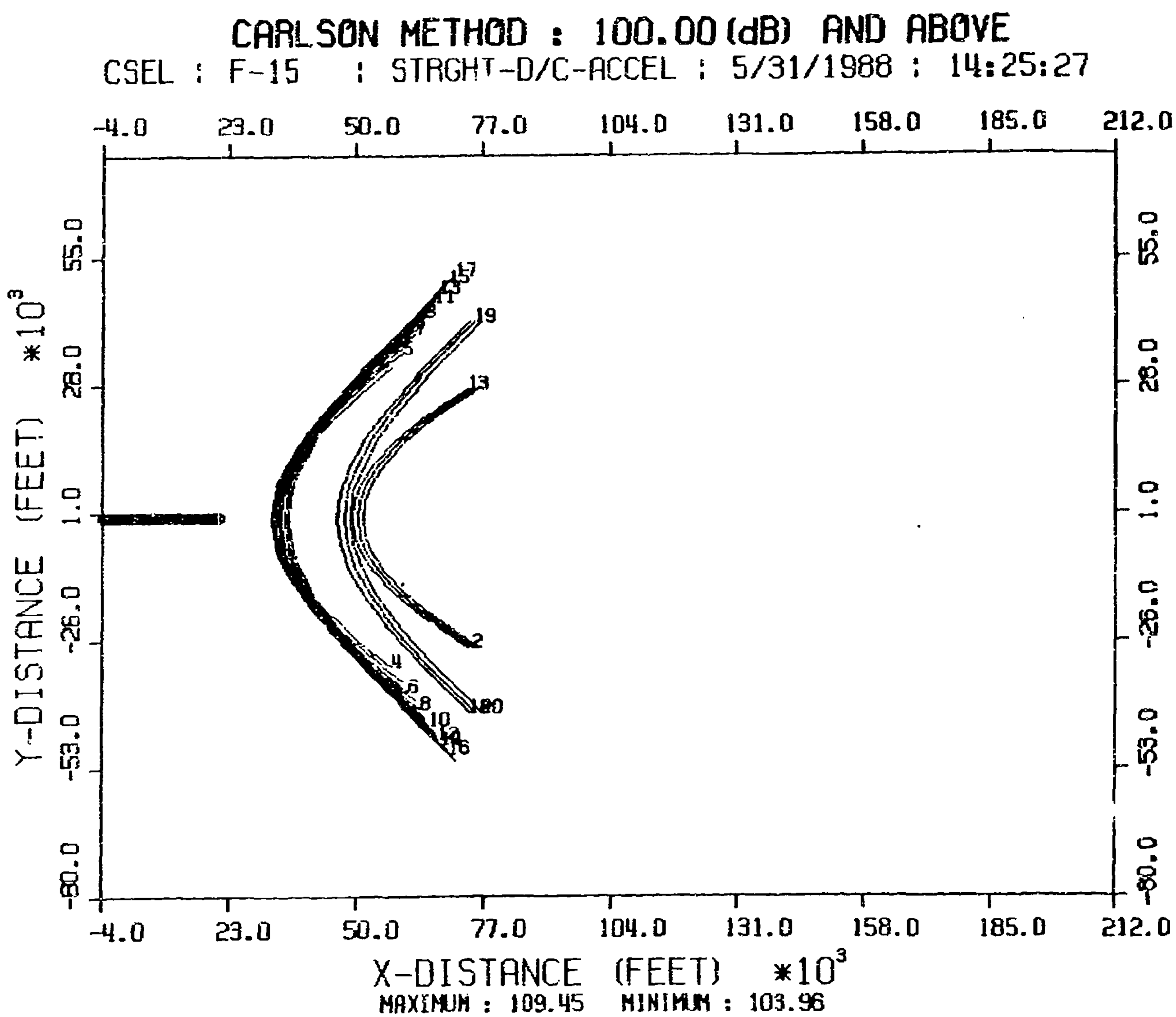

FIGURE A-9(b). FOOTPRINT PLOT FOR STRAIGHT FLIGHT WITH DIVE AND SPEED CHANGE EXAMPLE

RAY-TRACE METHØD

CSEL ¦ F-15 ¦ D/C TURN-NØACCEL ¦ 5/27/1988 ¦ 20:16:1

AIRCRAFT
****

F-15

42.30 KLBS

63.80 FT

SHAPE FACTØR : 0.0838

USER INPUT
****

ALTITUDE : 25000.0 FT

GRØUND HEIGHT : 0.0 FT

MACH NUMBER : 1.30

TURN ANGLE : 15.00 DEGREES

TURN RATE IN G'S : 1.30

FLIGHT TRACK ANGLE : 0.00 DEGREES

FIGURE A-10. TITLE SHEET FOR CONSTANT SPEED TURN IN LEVEL FLIGHT EXAMPLE

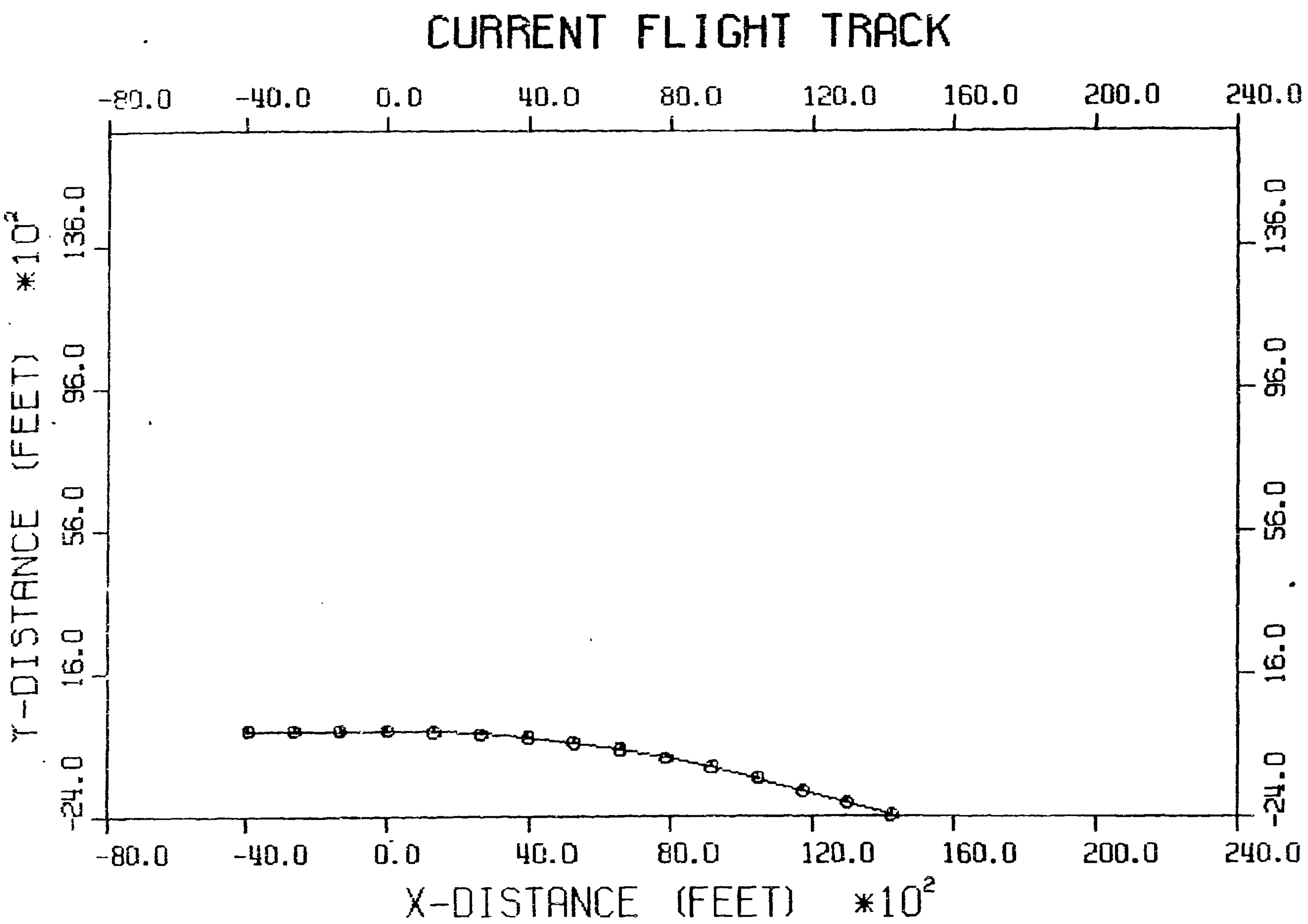

FIGURE A-11. FLIGHT TRACK PLOT FOR CONSTANT SPEED TURN IN LEVEL FLIGHT EXAMPLE

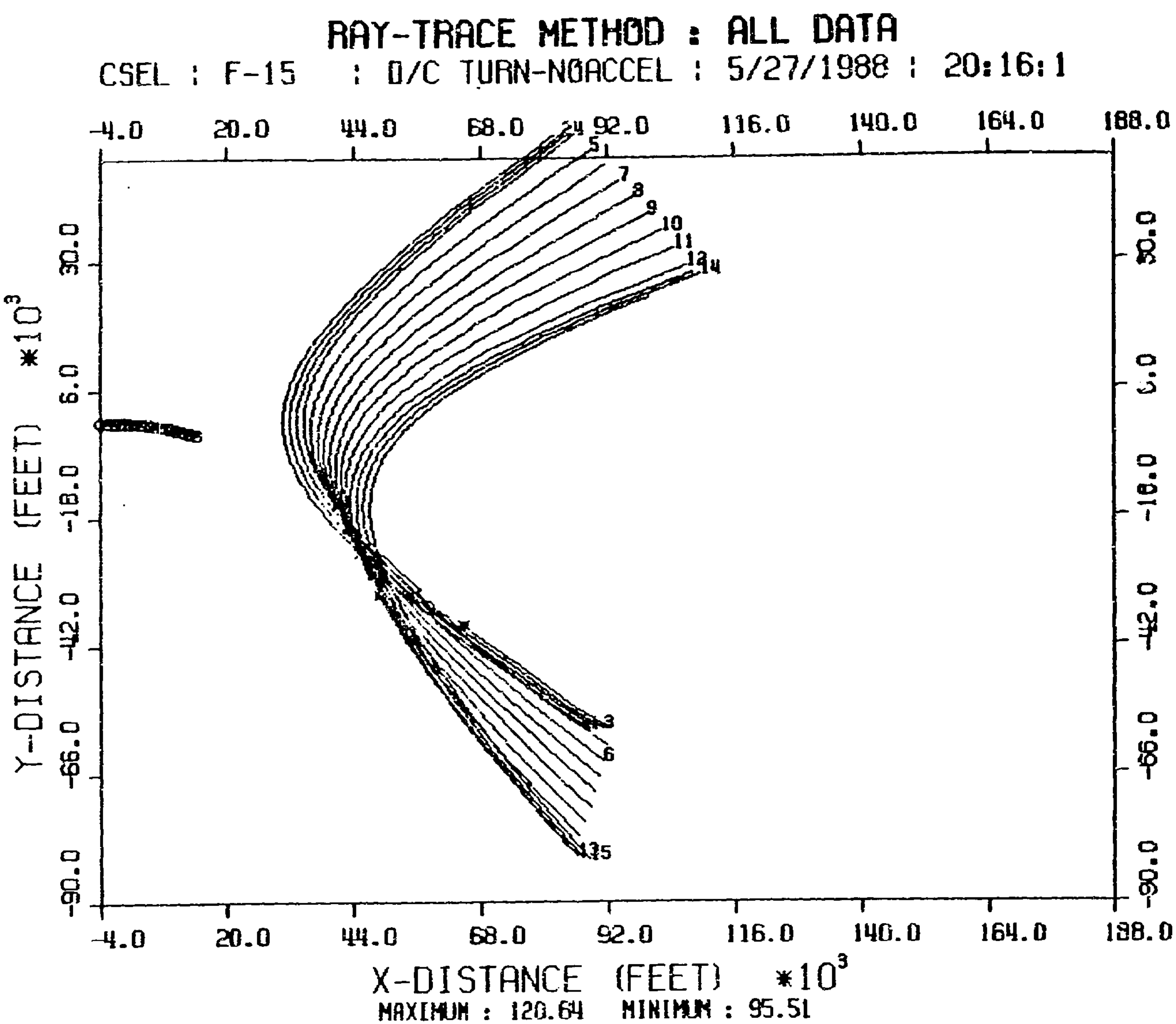

FIGURE A-12(a).FOOTPRINT PLOT FOR CONSTANT SPEED TURN IN LEVEL FLIGHT EXAMPLE

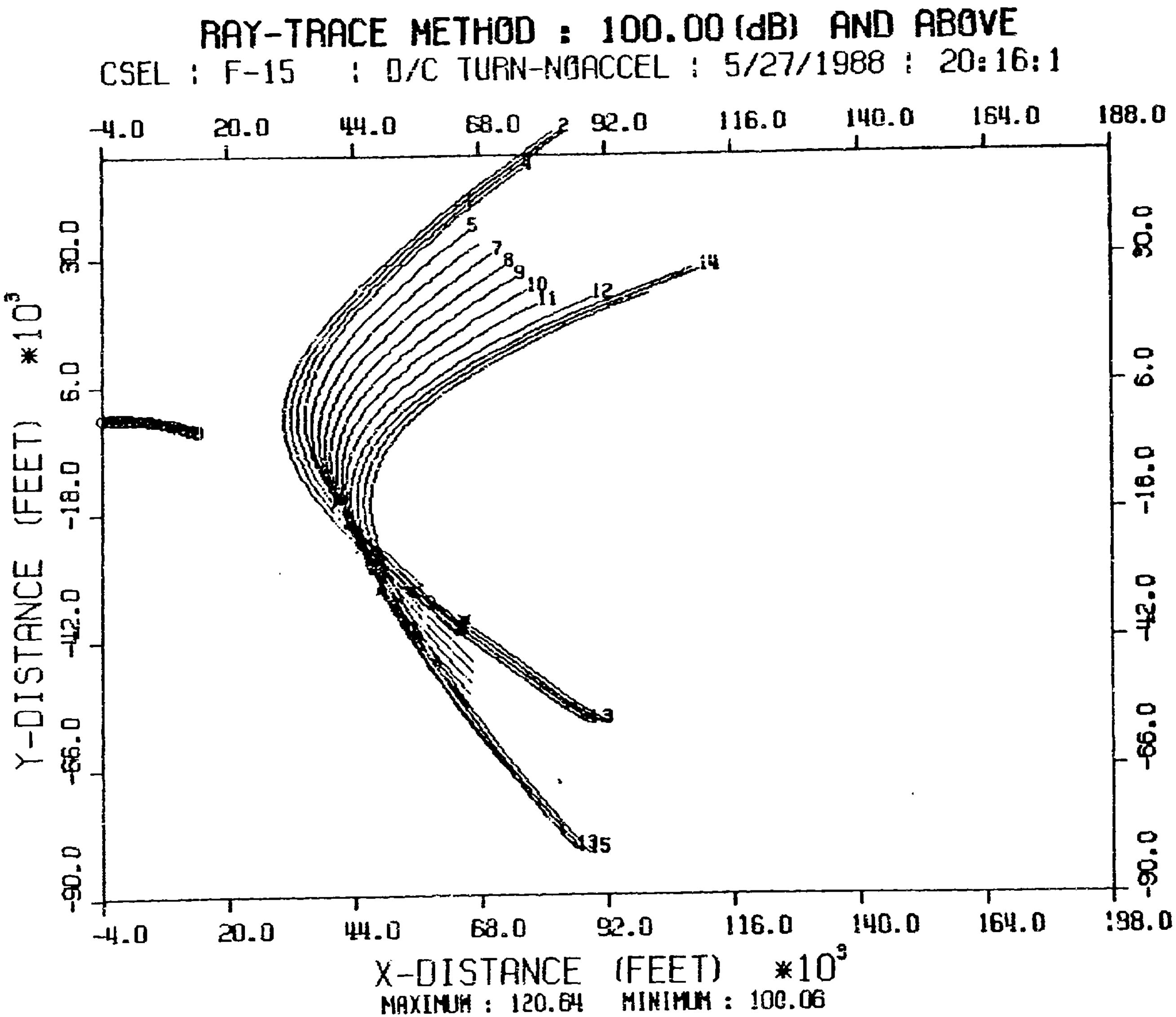

FIGURE A-12(b). FOOTPRINT PLOT FOR CONSTANT SPEED TURN IN LEVEL FLIGHT EXAMPLE

```
                    CARLSØN METHØD
CSEL ¦ F-15   ¦ D/C TURN-NØACCEL ¦ 5/27/1988 ¦ 16:15:8


AIRCRAFT
********
F-15
42.30 KLBS
63.80 FT
SHAPE FACTØR : 0.0838

USER INPUT
**********
ALTITUDE           : 25000.0 FT
GRØUND HEIGHT      : 0.0 FT
MACH NUMBER        : 1.30
TURN ANGLE         : 60.00 DEGREES
TURN RATE IN G'S   : 1.30
FLIGHT TRACK ANGLE : -10.00 DEGREES
```

FIGURE A-13. TITLE SHEET FOR CONSTANT RADIUS TURN AND DIVE AT CONSTANT SPEED EXAMPLE

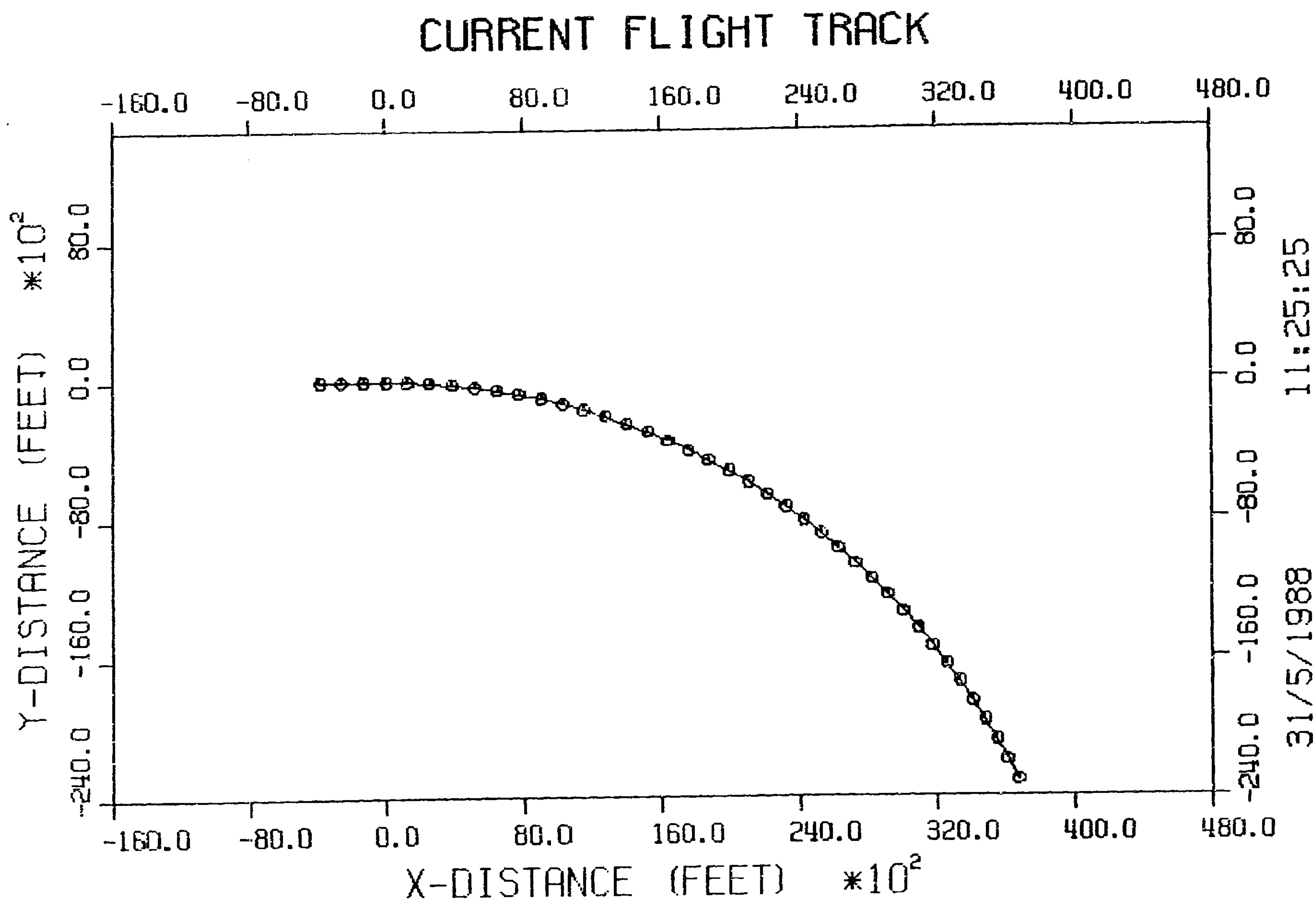

FIGURE A-14. FLIGHT TRACK PLOT FOR CONSTANT RADIUS TURN AND DIVE AT CONSTANT SPEED EXAMPLE

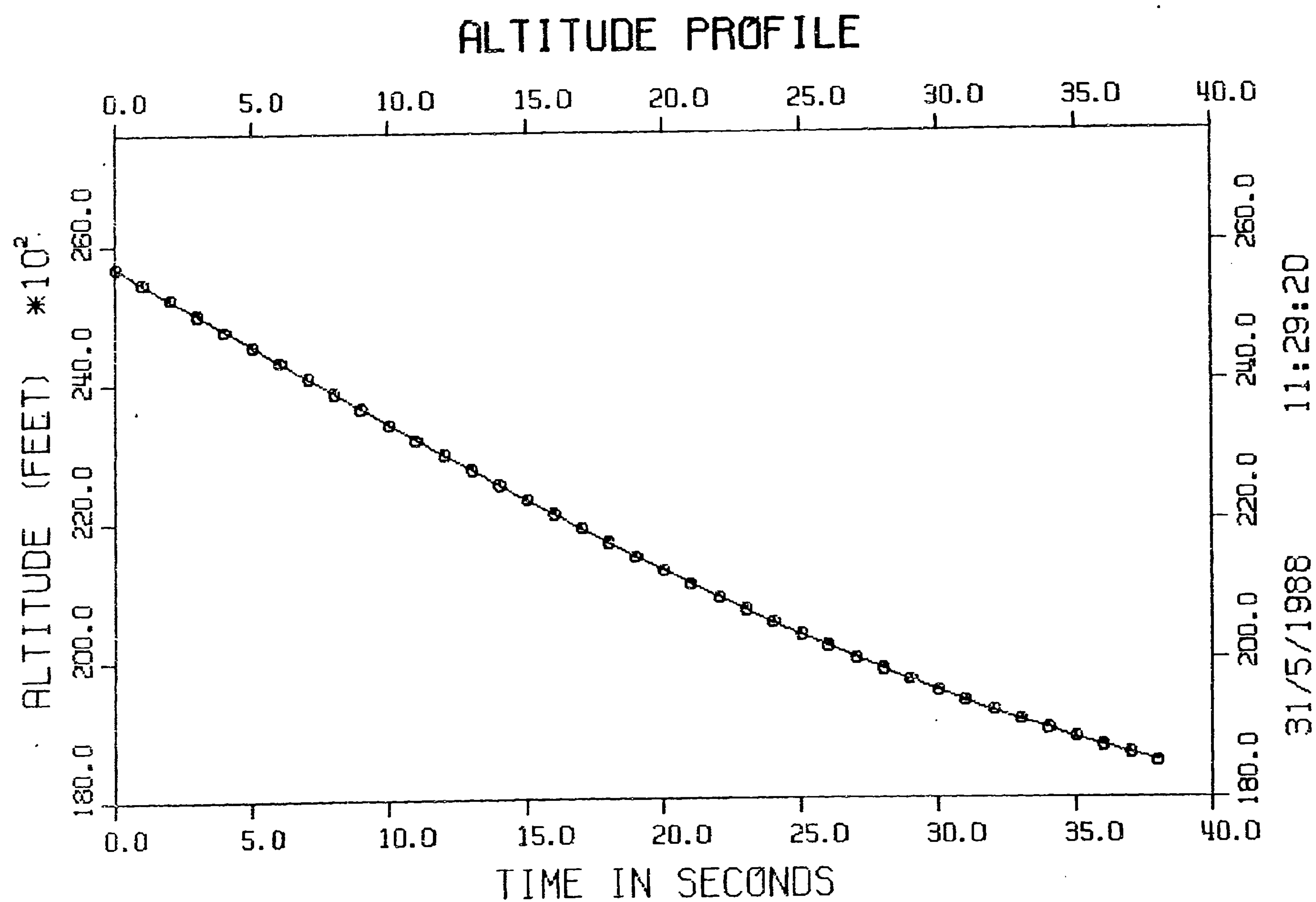

FIGURE A-15. ALTITUDE PROFILE FOR CONSTANT RADIUS TURN AND DIVE AT CONSTANT SPEED EXAMPLE

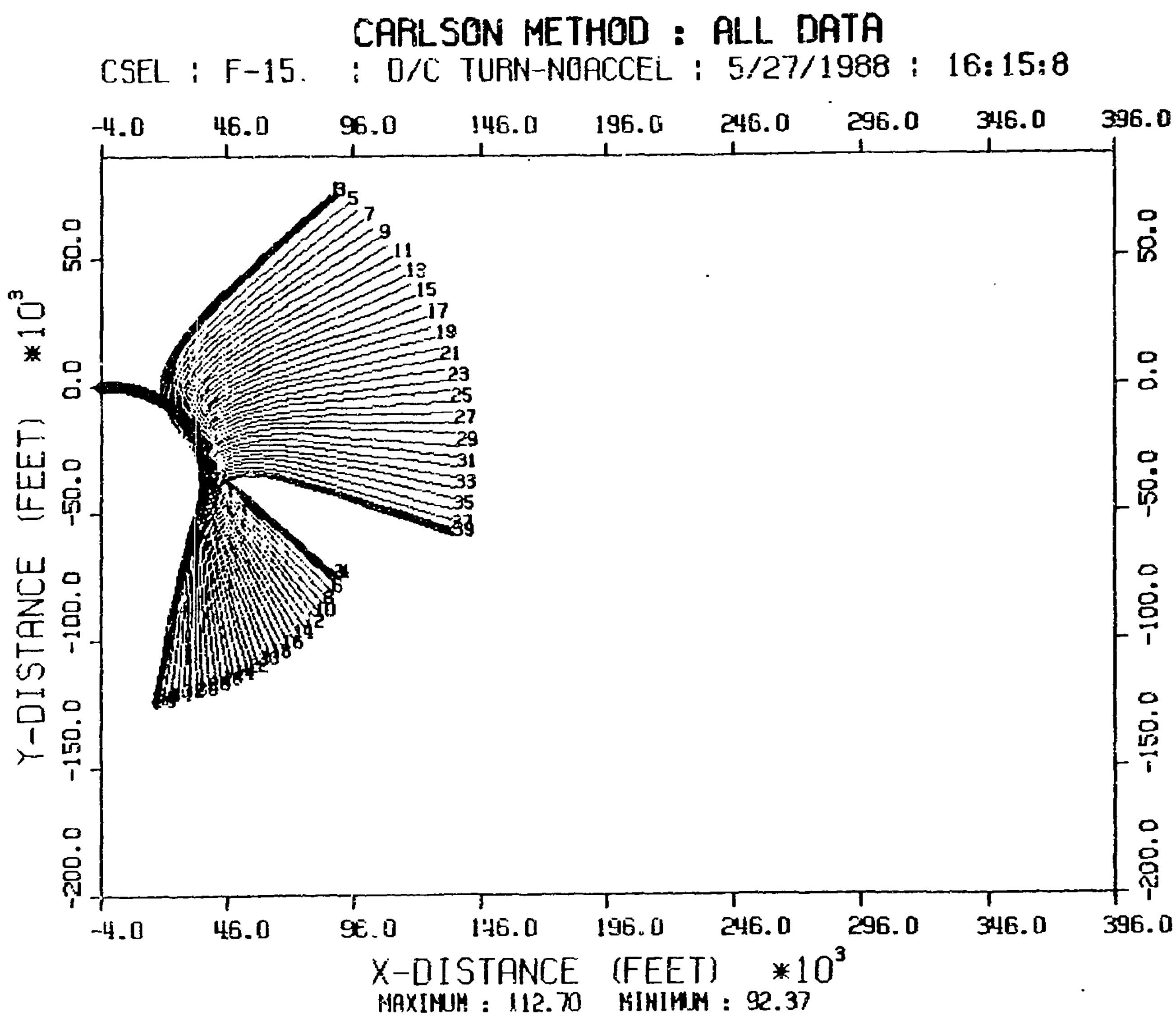

FIGURE A-16(a). FOOTPRINT PLOT FOR CONSTANT RADIUS TURN AND DIVE AT CONSTANT SPEED EXAMPLE

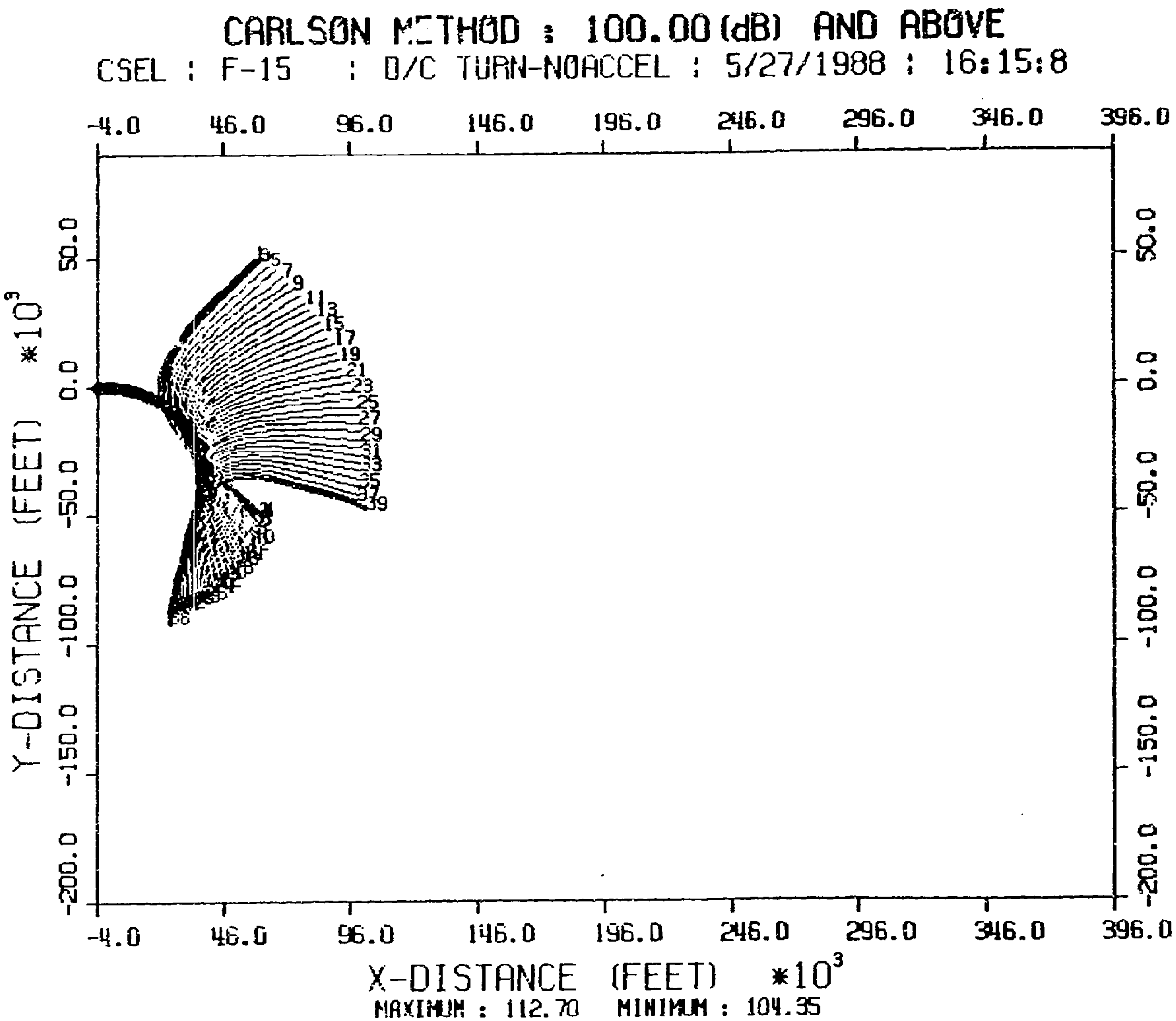

FIGURE A-16(b). FOOTPRINT PLOT FOR CONSTANT RADIUS TURN AND DIVE AT CONSTANT SPEED EXAMPLE

```
                 CARLSON METHOD
CSEL | F-15   | SEGMENTED TRACK  | 5/31/1988 | 12:1:22


AIRCRAFT
********
F-15
42.30 KLBS
63.80 FT
SHAPE FACTOR : 0.0838

USER INPUT
**********
NUMBER OF SEGMENTS : 4
GROUND HEIGHT      : 3000.0 FT
ALTITUDE'S (FT)    : 25000.0, 25000.0, 30000.0, 30000.0, 25000.0
MACH NUMBERS 'S    : 1.20, 1.20, 1.15, 1.25, 1.35
CLIMB/DIVE ANGLE'S : 0.0, 0.8, 0.0, -0.6
TURN ANGLE'S (DEG) : 0.0, 20.0, 20.0, -30.0
DISTANCE'S (MILES) : 40.0, 60.0, 40.0, 80.0
LENGTH'S (SECONDS) : 197.3, 305.3, 201.3, 368.0
```

FIGURE A-17. TITLE SHEET FOR CONNECTED STRAIGHT FLIGHT TRACK SEGMENTS EXAMPLE

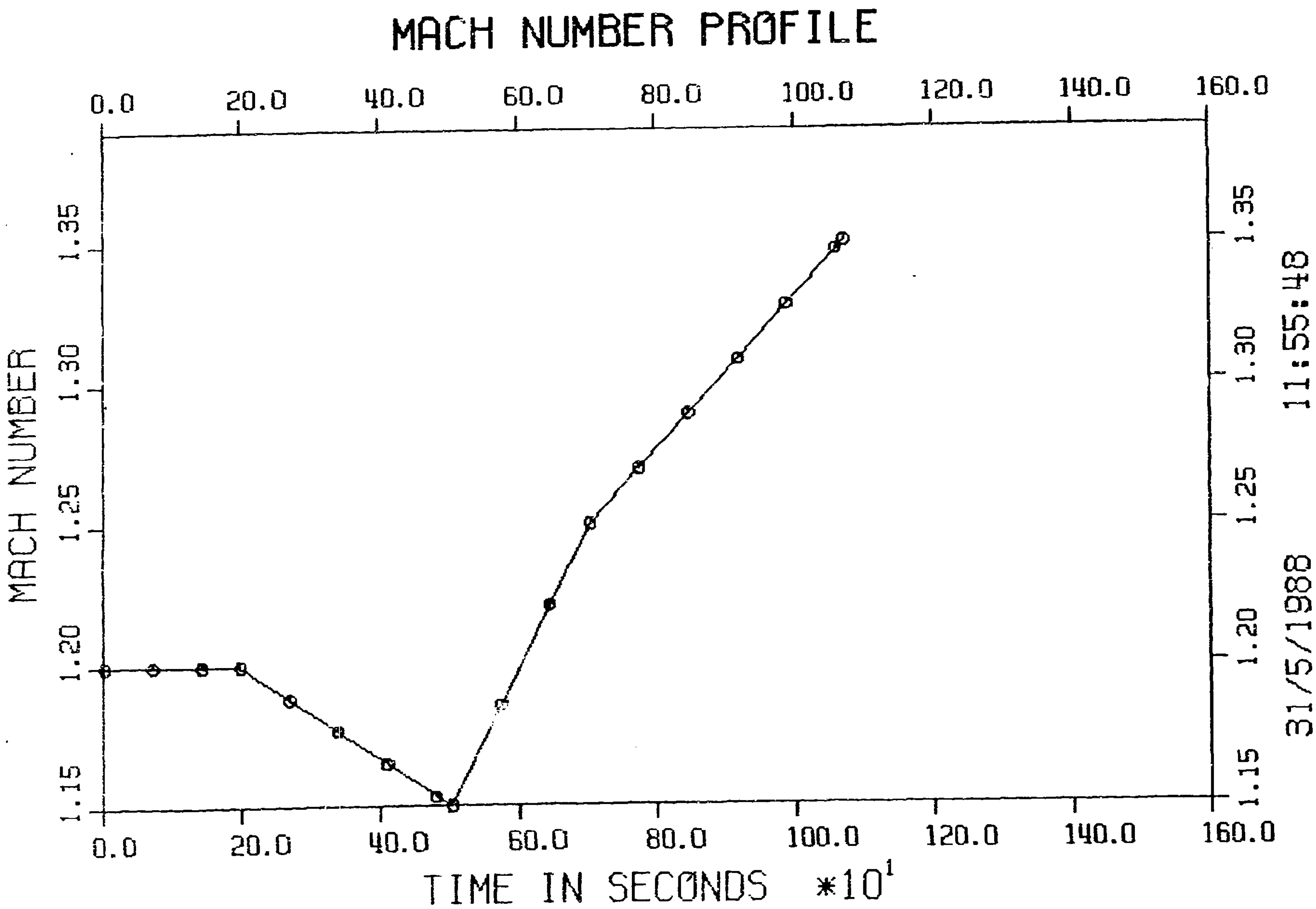

FIGURE A-18. MACH NUMBER PLOT FOR CONNECTED STRAIGHT FLIGHT TRACK SEGMENT EXAMPLE

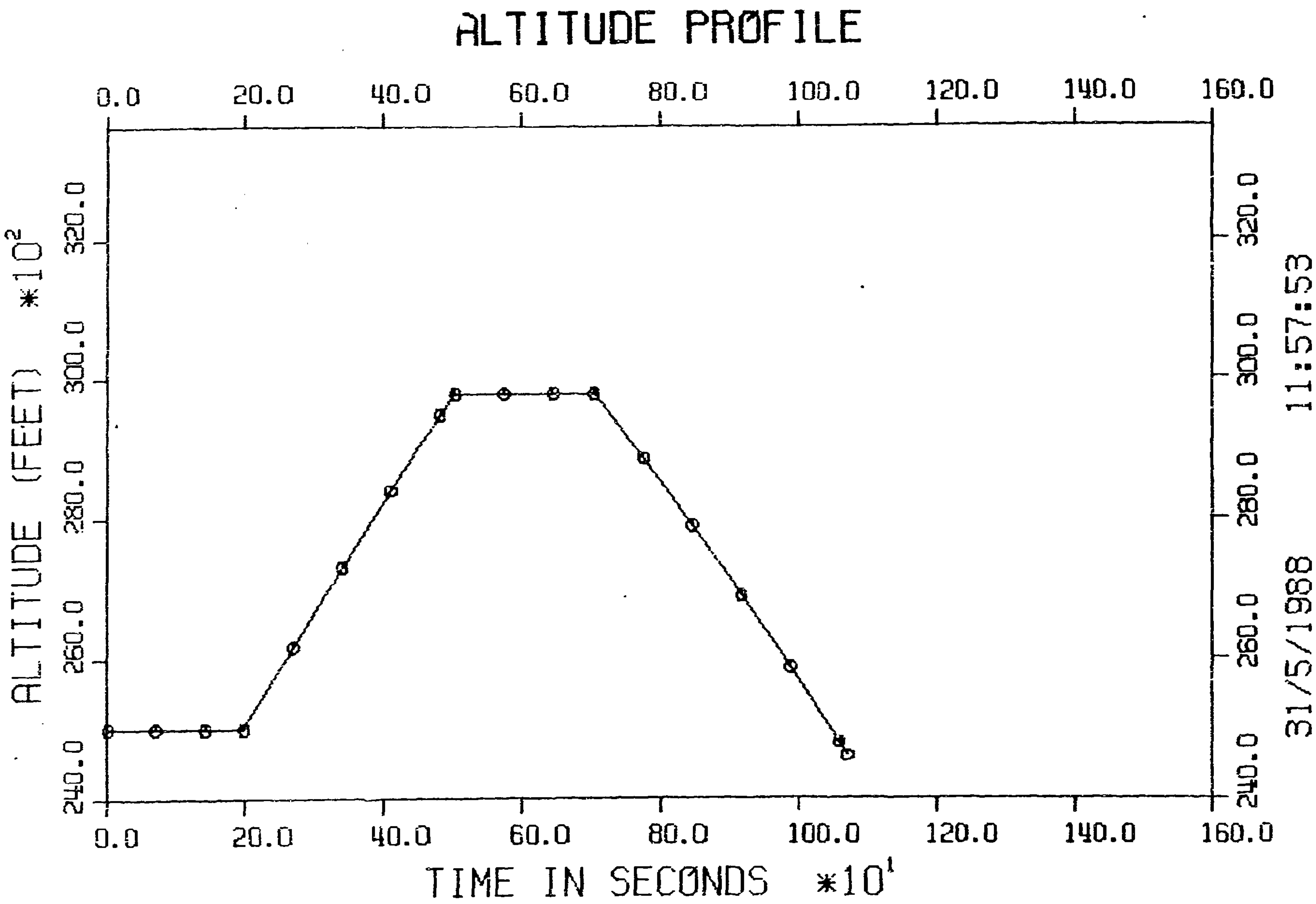

FIGURE A-19. ALTITUDE PLOT FOR CONNECTED STRAIGHT FLIGHT TRACK SEGMENT EXAMPLE

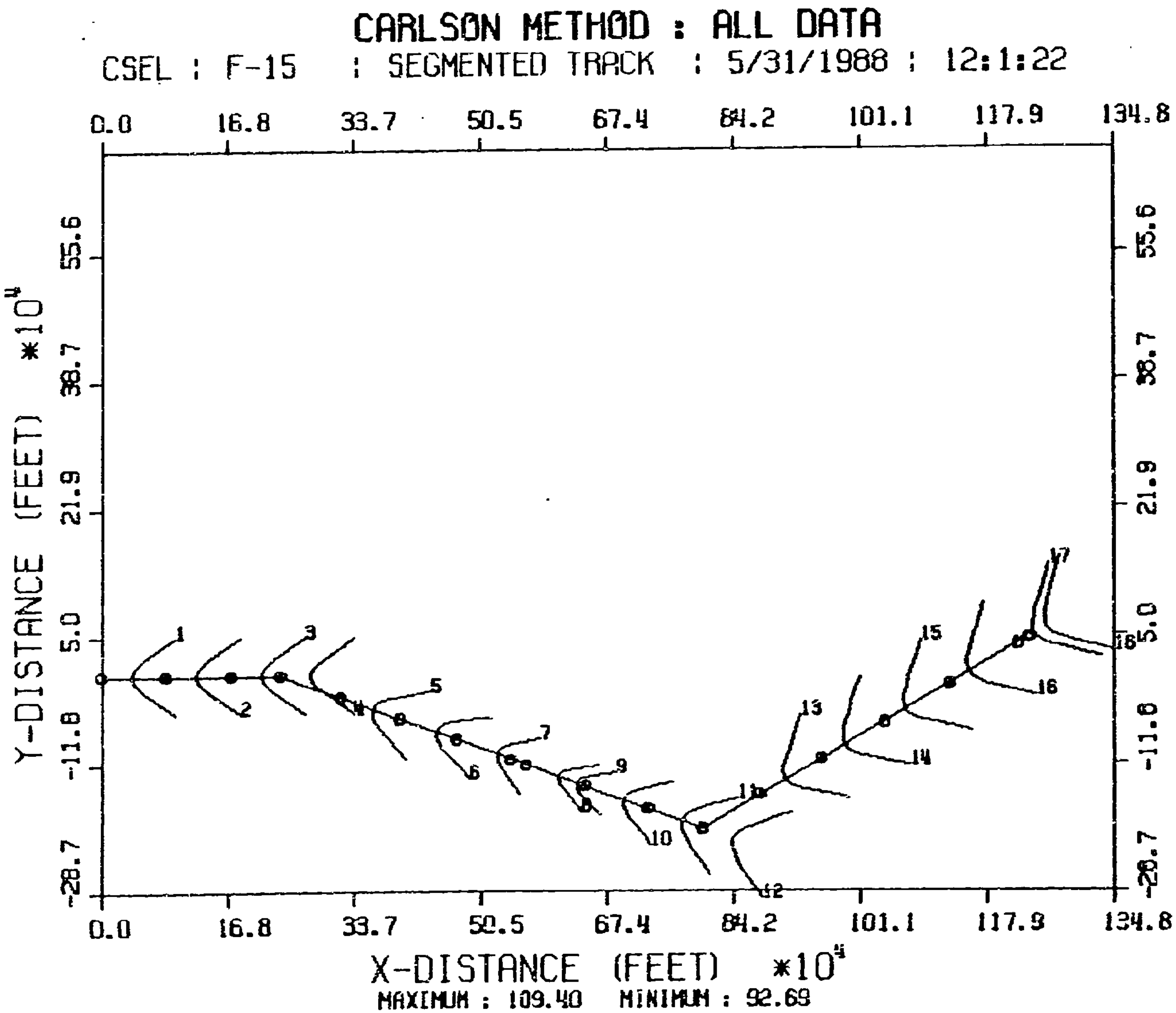

FIGURE A-20. FOOTPRINT PLOT FOR CONNECTED STRAIGHT FLIGHT TRACK SEGMENT EXAMPLE